한국소음진동공학회 2009년 춘계학술대회논문집, pp.256~257

스마트 압전 패치를 이용한 임피던스 기반의 콘크리트 압축 강도 발현 모니터링

Impedance-based Compressive Strength Gain Monitoring of Concrete Using Smart PZT Patches

신성우† · 존 파퍼비치*
Sung Woo Shin and John S. Popovics

1. Introduction

Recent advances in smart sensor technologies have provided various tools for structural health monitoring of civil engineering structures and introduced a concept of smart structures [1]. Especially electro-mechanical impedance (EMI) based active sensing technique utilizing smart piezoelectric materials have been emerged as a potential tool for the implementation of a built-in online monitoring system for civil infrastructures [2]. However most of EMI sensing research primarily focused on the application in damage detection but it has not been applied for the quality assessment of cement-based construction materials, for example, strength gain assessment of early-age concrete.

In this study, the feasibility of the EMI sensing technique for the online strength gain monitoring of early age concrete is investigated. Smart piezo-ceramic (PZT) patches having high stiffness and piezoelectric strain coefficients ideally suited for monitoring concrete structures are used to sense the EMI signatures in this study. An experimental study is conducted on the piezoelectric patch instrumented concrete specimens and the results are analyzed for that purpose.

2. Experimental Study

2.1 EMI Sensing Principle

Basic principle of the EMI sensing technique is to track an electrical impedance of the piezoelectric patch bonded onto the structure [2]. The PZT patch attached to the structure couples the mechanical impedance of the structure to the electrical impedance. Any change of the mechanical properties in a structure causes changes in the mechanical impedance, and also induces changes in the electrical impedance of the PZT patch bonded to the structure. In this study, this coupling property of the PZT patch is utilized for strength monitoring which is based on the measuring of the mechanical impedance.

2.2 Experimental Setup

Concrete cylinder specimens with a diameter of 100 mm and a height of 200 mm, which is normally used for compressive strength evaluation, were prepared for this experiment in a total of 16 concrete specimens (1 for EMI signature acquisition and 15 for compressive strength tests) comprising of Type I Portland cement (C), water (W), well-graded washed sand (FA), and gravel coarse aggregate (CA). The mixing proportion of the concrete is 1:0.45:2.40:2.66 (C:W:FA:CA, ratio by mass of cement) and the design strength is 21 MPa. All specimens were stored in moisture and temperature controlled curing room until testing.

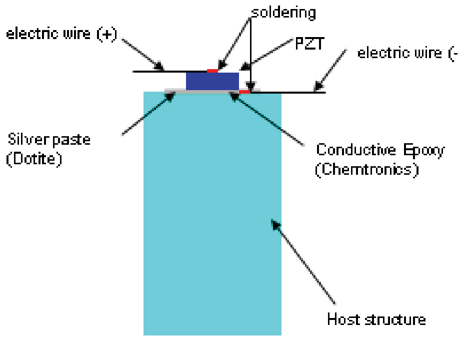

Figure 1. Configuration of PZT Instrumented Concrete Specimen

A size of 10 x 10 x 0.2 (*mm*) square PZT patch was instrumented on a cylinder specimen as shown in Figure 1. The attachment of PZT was done 1 day after casting the cylinder specimens. The first testing was carried out at the age of 3 days in order to ensure full curing of PZT bonding adhesive. Compressive strengths were evaluated at the ages of 3, 5, 7, 14 and 28 days. Days 3, 7, and 28 are the important days in evaluating in-place compressive strength specified in many construction codes. Three specimens were evaluated at each age to

---

† 교신저자; 부경대학교 공과대학 안전공학부
E-mail : shinsw@pknu.ac.kr
Tel : (051) 629-6473, Fax : (051) 629-6463
* Civil and Environmental Engineering, University of Illinois at Urbana-Champaign, USA

obtain average compressive strength. EMI signatures were also acquired at the same ages. Impedance analyzer (HP 4294A) was used for EMI signature acquisition. In order to minimize incoherent noise components, the signatures were acquired with 10 repeated measurements and averaged.

2.3 Results and Discussions

Figure 2 shows the average conductance signatures of the PZT at the ages of 3, 5, 7, 14, and 28 days corresponding to the days of compressive strength tests. It is obviously observed that the signatures gradually shift to the right and downward direction as the curing day increases. The magnitude and location of the resonant peak is reduced and shifted to the right direction. Increasing in the mechanical impedance (and hence strength) of early age concrete restrains the vibration of the bonded PZT and changes the resonant frequency of PZT-structure interaction system. Therefore, the behavior of EMI signatures in this study is on account of the strength gain action of concrete during curing. This result verifies the feasibility of EMI sensing technique for strength gain monitoring.

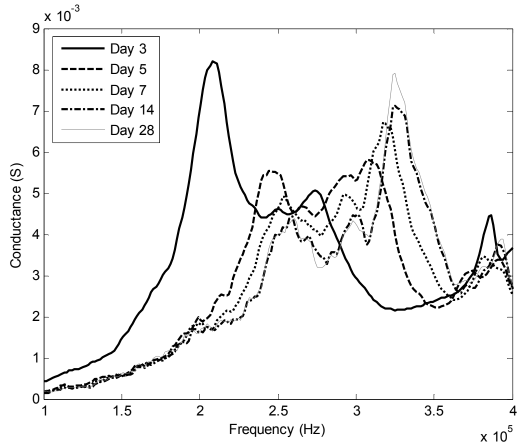

Figure 2. Measured conductance (inverse of impedance) signatures at the days of compressive strength tests

Compressive strengths were evaluated at the same test days and they are compared with the estimated resonant frequencies as shown in Figure 3. The estimated resonant frequency is shown to correlate very well with the compressive strength. The largest amounts of change in both the resonant frequency and strength are observed between day 3 to day 5 and the amounts decrease sequentially up to day 14. The change of the resonant frequency is not much than that of the strength from day 14 to day 28. This suggests that the resonant frequency may be used as a sensitive indicator to monitor the strength gain of concrete up to day 14.

3. Conclusion

The feasibility of the EMI sensing technique for strength gain monitoring of early-age concrete is presented in this study. According to the experimental results, it was observed that the EMI signature is sensitive to the strength development of early-age concrete. The EMI signature gradually shifts to the right and downward direction as the curing day and the strength increases. It is also found that the resonant frequency has a strong correlation with the strength development in early age concrete. Therefore, the resonant frequency may be used as a suitable and sensitive indicator for the strength gain monitoring of the early age concrete.

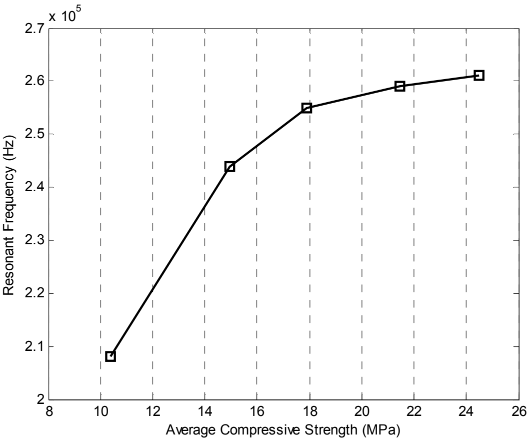

Figure 3. Comparison of average compressive strengths and resonant frequencies

Acknowledgements

This work was supported by the Korea Research Foundation Grant (Grant # KRF-2007-357-D00247) funded by the Korean Government (MOEHRD). The first author greatly acknowledges for this financial support.

References

[1] S.C. Liu, M. Tomizuka, and G. Ulsoy, “Strategic Issues in Sensors and Smart Structures”, *Structural Control and Health Monitoring*, Vol.13 (6), pp. 946-957, 2006

[2] G. Park, H. Sohn, C.R. Farrar, and D.J. Inman, “Overview of Piezoelectric Impedance-Based Health Monitoring and Path Forward”, *Shock and Vibration Digest*, Vol.35 (6), pp. 451-463, 2003